# PATENT SPECIFICATION

## (54) GEAR PUMPS AND POLYMER PRODUCING AND RECOVERY, COMPOUNDING AND FABRICATING SYSTEMS USING THE PUMPS

(71) We, UNION CARBIDE CORPORATION, a corporation organized and existing under the laws of the State of New York, United States of America, of 270 Park Avenue, New York, State of New York, 10017, United States of America, (assignee of Isaac Moked; Richard Herman Handwerk and Walter Renquist Marshall), do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

The present invention relates to processes for producing and systems for handling polymers and more particularly to systems for handling compositions of polymers and volatile constituents, such as polyethylene and ethylene, and means for increasing the efficiency of compounding systems for these compositions, and to a pump employed in such systems.

As employed herein, the term "polymer(s)" is understood to mean organic homopolymers, copolymers, and polymeric mixtures either alone or containing additives of the type normally encountered in the plastics field, e.g., stabilizers, fillers, processing aids, colorants and other additives (such as anti-block, anti-oxidation, anti-static and the like).

In the typical production of low density polyethylene, a reactor discharges a stream which is a mixture of polymer and unreacted materials to a product receiver. The product receiver operates at a pressure substantially below the reactor pressure and flow of the reactor discharge is controlled by the product valve. In the product receiver, the major portion of the unreacted materials are removed due to flashing which results from the drop in pressure experienced by the mixture. The flashed material, commonly referred to as the return gas, is subsequently returned to the reactor. The remaining polymerized material settles in the product receiver and still contains some unreacted materials which are removed in the remainder of the polymer recovery system.

The polymer discharged from the product receiver is fed to an extruder through a polymer flow control system. The extruder performs two functions in this system: final devolatilization to remove the remaining unreacted material; and pumping of the polymer through a screen pack, if one is being used, and a pelletizer die plate.

The material enters the side of the extruder and the unreacted materials flash and form a foam having a very low density. Therefore, an extruder having a very large volumetric conveying capacity in the feed section is necessary to handle the material as final devolatilization is occurring. Normally, an extruder having a two-diameter screw or an oversize single-diameter screw is required to obtain the conveying capacity to handle the material entering the extruder. In some installations, a portion of the flashed material is removed from the extruder through a vent stack.

As the production rate of single low density polyethylene (LDPE) reactors are increased, larger and larger extruders, which become prohibitively expensive, are needed. In an effort to eliminate the use of two-diameter extruders or oversized extruders, some existing units have been modified to include a secondary ethylene separation (flashing) operation upstream of the extruder inlet subsequent to the primary product receiver ethylene separation (flashing) operation.

This system differs from the side-fed extruder, top mounted vent stack type in that the material is fed into the top of the vent stack and essentially all of the remaining unreacted materials are released before the polymer stream enters the extruder. This provides a

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material to the extruder which has a much greater density and eliminates the need for
two-diameter extruders or large single-diameter extruders. The devolatilization and
pumping functions of the original, two-diameter extruder system have now been separated,
i.e. the final devolatilization is performed in the vent stack and only the polymer pumping is
performed by the extruder. However, extruders pump polymer by developing viscous drag,
and are very inefficient pumps.

There is provided by the present invention a gear pump for pumping highly viscous media
comprising: housing means defining an inlet passage at one end and an outlet passage at an
opposite end, and a chamber therebetween; a pair of pump gears located within said
chamber having intermeshing teeth and being rotatably mounted in said housing, the walls
of said chamber and said pump gears defining therebetween a free space to receive viscous
media, and a wall of said chamber and each of said gears defining a gear sealing zone
adjacent the outlet, each zone having a minimum length circumferentially of the respective
gear equal to the circumferential distance between two adjacent gear teeth across the full
axial length of said gears at the outside perimeter of said gears; the portion of said outlet
adjacent said sealing zones having a cross-sectional area of from 0.2 to 2.0 times the product
of the gear width and the gear tooth height.

The pump of the invention, to enable it to deal with a rope strand feed of a viscous
medium, may be provided with a pair of feed rollers rotatably mounted in said chamber
upstream of said gears, the axis of each roller being substantially parallel to the axis of the
associated gear and said rollers being spaced apart to define a media nip substantially
coplanar with the mesh line of said gears, and means for rotating said gears and rollers,
whereby said rope strand is drawn into and feeds the gear cavities and is thereafter pumped
by said gears.

As will be made evident below the pump may advantageously be employed in viscose
media compounding apparatus, in a polymer fabrication system and in a process of polymer
production.

The pump of the invention facilitates filling of the gear tooth cavities. Additionally, the
shear areas and energy dissipation in shear is an order of magnitude lower than comparable
positive displacement pumps. Horizontal gear axes orientation is preferred, but not
essential; and the outlet, which is sized to interface with the gear pump, is preferably
rectangular in shape with the major dimension parallel to the axes of the gears. The outlet
may, however, be circular, oval or of any other cross-sectional shape desired from the
operating standpoint.

The invention will now be further described by way of example with reference to the
accompanying drawings in which:-

Figure 1 is a schematic view of a low-energy polymer production system in accordance
with the present invention;

Figure 2 is an enlarged cross-sectional view of a gear pump for use in the low energy
system of Figure 1;

Figure 3 is a cross-sectional view with certain portions broken away for clarity taken
generally along line 3-3 in Figure 2;

Figure 4 is a top plane view taken generally along line 4-4 of the pump in Figure 2;

Figure 5 is a cross-sectional view of a gear pump with feed rollers for handling feed in
rope form;

Figure 6 is a sectional view taken along line 6-6 in Figure 5;

Figure 7 is a top plane view of the pump of Figure 5;

Figures 8A and 8B are schematic views illustrating compounding systems equipped with
the pump of Figures 2 and 5 respectively;

Figure 9 is a schematic view illustrating the use of a pump positioned in the inlet
combination with an extrusion die of the type discussed either in a process disclosed in a
single-diameter extrusion process;

Figure 10 is a cross-sectional view of an alternate gear pump with feed rollers in which the
entire inlet/gear cylinder section is replaced, removed from the extruder through the
discharge end of the extruder;

Figure 11 is a cross-sectional view where the gears and the inlet portion are both
two valves for increasing the size of the extruder to provide additional of the use of a
combination assembly, modified along 33-33 in Figure, be modified along
Figure 14 is a top plane view of a modular gear pump with feed rollers in which the gears
and rollers are modular for increasing the capacity of the pump;

Figure 15 is a cross-sectional view taken generally along line 15-15 in Figure;

Figure 16 is a cross-sectional view taken generally along line 16-16 illustrating an external to
the feed rollers;

Figure 17 is a side elevation view with certain portions broken away in cross-section
illustrating a completely modular gear pump embodiment; and

*Figure 18* is a front elevation view of the pump of Figure 17 with certain portions broken away in cross-section.

Figure 1 illustrates an integrated system for the production of low density polyethylene in accordance with the present invention. A composition of liquid polyethylene and entrained ethylene is produced in a reactor (not shown), as is well known in the art. The composition is discharged from the reactor through line 10 into a product receiver 12. The mixture flow to product receiver 12 is controlled by a product valve 14 and a pressure relief valve 16 in line 10. The bulk of the entrained ethylene gas is removed from the mixture by flashing in product receiver 12 and the thus removed ethylene gas is condensed and recycled to the reactor through line 12A for further use. The partially devolatilized polyethylene collects at the lower portion of product receiver 12 and is transferred through line 20 to the inlet of vent stack 22.

Transfer of the liquid polyethylene to the vent stack is accomplished by a pressure gradient which exists between product receiver 12 and vent stack 22. The product receiver operates at pressures in the order of 1000 p.s.i. or higher and the vent stack is operated at pressures at or slightly above or below atmospheric pressure. The flow rate of polyethylene to vent stack 22 is controlled by a feed control valve 24 in line 20, and a sufficient level of liquid polyethylene is maintained in the product receiver to prevent blow through of ethylene directly to the vent stack.

As the polyethylene enters vent stack 22, substantially all of the remaining entrained ethylene flashes from the mixture due to the pressure-equilibrium relationship at the pressure of the vent stack. The low pressure in the vent stack and removal of the ethylene is accomplished through a return line 26 which includes a pumping means 28, such as a venturi nozzle or vacuum line. The return fluid in line 26 is collected for further processing in the reactor.

Polyethylene melt P settles in the vent stack and is allowed to achieve a liquid level L. The lower portion of vent stack 22 is in fluid communication with a gear pump 30, described in greater detail below, through a tapered outlet portion 22A. The level of the liquid polymer in the vent stack is preferably maintained such that polyethylene-ethylene interface is above the pump inlet and the diameter of the vent stack is such that the pressure drop caused by the flowing polymer pool is equal to, preferably less than the pressure head formed by the liquid level of the polymer. Thus, gear pump 30 is flood-fed by the liquid polymer P in the vent stack.

Gear pump 30 is driven by a variable speed drive 32 and torque coupling 34 to withdraw polymer from the lower portion of the vent stack and pump it under pressure through conduit 36 into a pelletizer 38 for final processing and delivery of the polymer to product hopper 40.

Control of the system is provided by a central process control 42 which, in addition to monitoring the function and operation of the reactor, as is known in the industry, monitors and controls the above-mentioned equipment. More specifically, a liquid level controller 44, which may be either of the displacement or rate types, as discussed more fully below, senses the level (or rate of change of level) of polymer in the vent stack. This variable is utilized by the process control 42 to set the variable speed drive 32 to insure flood feed operation and full capacity capability of the pump. Also, the level control may be utilized to provide an indication of production rates, as discussed below.

Additionally, the process control unit monitors power input to the pump, and inlet and outlet pressures and temperatures at the pump through lines 46. The exact instrument for monitoring these variables are well known in the instrumentation art and include torque meters, pressure transducers, either mechanical or electrical, e.g., piezoelectric transducers and thermocouples or thermistors, respectively. From these measured variables on-line viscosity monitoring is achieved. Viscosity is inversely related to the product melt index which is a primary control variable for reactor control in the production of polymers. Thus, these measured variables are fed back in the process control unit 42 to provide control of polymer production in the reactor.

Figures 2-4 illustrate gear pump 30 specifically designed to provide a minimum net positive suction head and improved polymer pumping capability. Pump 30 is modular in construction and includes an inlet structure 50, gear housing 52, and steam jacket 54. Inlet structure 50 includes two plate-like elements 50A and 50B of generally L-shaped configuration and having interlocking end portions 50C and 50D as best illustrated in Figure 4. Inlet structure 50 is coupled to a peripheral flange 22B on the outlet of vent stack 22A and to gear housing 52 by a plurality of fasteners 56, Figure 2.

Gear housing 52 is generally rectangular in outer dimension and includes an upper flange portion 52A, which abuts against the lower surface of inlet structure 50, and sidewalls which define a gear chamber 58 at their inner surface and taper downwardly at two opposite outer surfaces 60 to define the inner surface of a steam chest. The steam jackets 54 are removably

mounted to the gear housing 52 by means, not shown, and complement the tapered sides 60 to form a steam chest about the gear pump. The steam jackets include a steam inlet 54A and condensate outlet 54B for admitting steam from a source (not shown) to maintain the pump at a temperature above the melting temperature of the polymer. Alternatively, passageways such as drilling, described below, may be utilized in a solid pump body configuration.

Referring particularly to Figures 2 and 3, inlet structure 50 defines an inlet 66 whose width (parallel to the gear axis) is approximately equal to the gear width, Figure 3, and whose minimum length (normal to the gear axis) taper downwardly to complement the gear chamber 58.

A pair of rotating, intermeshing gears 70 are positioned in gear housing 52. Any one of a wide variety of gear pairs may be employed, intermeshing herringbone gears being preferred.

As shown in Figure 3, a pair of intermeshing herringbone gears 70 are rotatably mounted in gear housing 52 by means of journal bearings 71 and end plates 72. One of the gears (the drive gear) includes a drive shaft 70A which extends outwardly from the gear pump to be coupled to the torque coupling 34 and thereby provide power input to the pump. The other gear is driven by the intermeshing relationship of the herringbone gears.

Journal bearings 71 are lubricated by the polymer melt, and as discussed below provide a means for monitoring the viscosity of the polymer melt. The length and diameter of the bearings and clearances are such that high pressure leakage is minimized by a throttling effect.

The chamber 58 in which the intermeshing gears 70 are located is designed to achieve an inlet of minimum restriction of polymer flow to improve volumetric efficiency. Substantially all of the faces of the gears are exposed to the media free space (the volume between the gear faces and walls of chamber 58). This configuration permits the development of a pressure gradient within the media free space to facilitate the filling of the gear tooth cavities with polymer.

To achieve the necessary large media free space and still provide the necessary seal between the outlet 103 and the low pressure inlet of the pump, the pump discharge opening 103 and seal zone 74 must be minimized. The portion of outlet 103 in direct communication with the gear chamber defines a generally rectangular shaped opening having a width 103A, Figure 3, equal to the gear face width and a length 103B, Figure 2, equal to about the gear tooth height.

The outlet is defined, in part, by high wear resistant seal zone inserts 75, which are removably secured to a seat 58A in the gear housing as by bolts, not shown. Each seal zone extends from the tip 75A of the inserts 75 for a circumferential distance at least equal to the distance between adjacent teeth across the full axial length of the gears to provide an effective seal between the gear teeth and gear housing. The start of the seal zone is generally indicated by numeral 75B, and the seal extends to tip 75A. It should be noted that a seal length larger than that just specified does not significantly increase seal effectiveness.

The inner surface of chamber 58 increases in dimension from the start of the seal 75B in a continuous smooth curve to join the inlet structure chamber 66 just above the top of gears 70. In one pump embodiment the gear chamber or media free space boundary extended from a location 75B 53° below the horizontal passing through the center of gear axis in a circular arc to a location 15° below the horizontal to provide a radial distance between the tooth tip and chamber surface of 1/2 inch at that point, and extended linearly from the 15° point to the top of the pump. In general, the ratio of free media space expansion to the circumferential distance (as measured from the end of seal zone 75B) is optimized in accordance with lubrication theory to achieve an increasing hydraulic radius in the media free space to fill the gear tooth cavities with polymer. The media free space increases from the seal zone 75B to produce a maximum pressure gradient at a point preferably below the horizontal elevation of the gear axes. The optimal media free space configuration is a function of the particular polymer being pumped. A ratio of the clearance (gear tooth to chamber wall) to the circumferential distance from the seal zone in the range of about 0.2 to 0.9 is a typical value for polymers having viscosities in the range of 0.2 to 1.4 lb. sec/in$^2$, respectively.

With particular reference to Figures 2 and 3, the outlet 103 changes from the slot-like opening adjacent the gears to a circular discharge outlet 103C at its lower end, which is in fluid communication with conduit 36.

The herringbone gears 70 may have helix angles ranging up to 30°; however, smaller helix angles, 15° or less, are preferred to avoid leakage at gear intermesh. Most preferably, herringbone gears with a helix angle of 7°-10° are used to avoid trapping polymer in the tooth cavities. The use of herringbone pattern gears is preferred to constant helical or spur gears due to reduced stress loading on the gears and housing realized with the herringbone

gears.

The use of a gear pump and more particularly a gear pump with herringbone gears provides economic savings in capital cost, operating cost and improved performance in comparison to screw extruders used for the polymer recovery system. More specifically, for a recovery system capable of handling 30-50,000 lbs/hr, system investment cost may be up to 50% less for a gear pump equipped system. In gear pump recovery systems for the indicated capacities, horsepower requirements ranged from 7 to 17 horsepower as opposed to 35 to 60 horsepower for a comparable extruder system. A comparable reduction in shaft horsepower equates to an annual cost savings for a 50,000 lb/hr system in the order of $150,000/year assuming 3.6 cents/kw. hr. electric costs.

Finally, the viscous shear dissipation work is greatly reduced by the use of the gear pump as compared to a screw extruder. The reduction in this work is about one order of magnitude. This reduction, of course, results in a reduction in the temperature rise of the polymer as it passes through the gear pump. Steady state temperature rises of 1° to 4°C have been experienced with the gear pump of this invention, as compared to 10° to 35°C for a comparable screw extruder. The reduced temperature rise provides better product property control and less thermal degradation of the polymer product.

The gear tooth helix angle and media free space of the gear pump provide improved handling and volumetric efficiency. Table I indicates a comparison of operating parameters for several configurations which illustrate the effects of gear tooth angle and media free space on gear pump performance. The body types include the one described above and designated as "FULL" and one designated "MIN" which had a media free space inlet dimension located 25° above the horizontal gear axis and extended therefrom in a circular arc to a location 20° below the horizontal gear axis (the start of the seal zone). Each unit was equipped with herringbone gears with the indicated helix angles and identical outlet shapes.

From Table I, it will be noted that the FULL media space configuration, i.e., the least restricted inlet configuration, provided volumetric capacities which were essentially constant for the range of product tested. The gear pump of the present invention is essentially insensitive to viscosity and pressure conditions with respect to its pumping capacity, and its volumetric efficiencies are essentially 100% over a range of gear pitch line velocities up to 150 ft/min.

The designations MIN and FULL as well as the characteristics of the pump structure given in connection with Table I are illustrative embodiments and should not be interpreted as setting forth the limits of applicants' invention. The values listed in the first six columns from left to right represent short tests for peak performance of the gear pump, while the last two columns represent long term steady-state operating conditions for a reactor system having the indicated production rates.

An additional advantage of the gear pump is increased recovery system operation. Unlike a screw extruder system which is highly sensitive to polymer viscosity, the gear pump being a positive displacement pump will continue to pump even if large changes in viscosity are experienced. An extruder on the other hand, would have to be shut down and cleaned, when high or low viscosity are introduced into it. Thus, reactor down time is decreased and reliability is greatly increased with the gear pump.

TABLE I

| Body Type | Min. | Min. | Min. | Full | Min. | Full | Full | Full |
|---|---|---|---|---|---|---|---|---|
| Gear Angle (Degrees) | 30 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Melt Index | 5.7 | 5.7 | 2.1 | 2.1 | 0.1 | 0.1 | 0.1 | 2.1 |
| Rate (lbs./hr.) | 10,000 | 9,000 | 8,500 | 9,000 | 7,600 | 8,700 | 3,300 | 3,010 |
| RPM | 120 | 103 | 101 | 101 | 94 | 97.6 | 37 | 34 |
| Lb./Rev. | 1.39 | 1.46 | 1.40 | 1.50 | 1.35 | 1.49 | 1.47 | 1.48 |
| Volumetric Efficiency (%) (Foam Density of 30 lb./ft.$^3$) | 93% | 97% | 93% | 99+% | 90% | 99% | 98% | 99% |
| T in (°C) | - | 277 | 270 | 260 | 280 | 271 | 281 | 273 |
| T out (°C) | - | 288 | 282 | 268 | - | 276 | 283 | 276 |
| P in (PSIG) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| P out (PSIG) | 850 | 850 | 1,400 | 1,350 | 2,800 | 3,100 | 1,970 | 820 |

As previously described, the gear pump recovery system includes instrumentation that measures pump input power and inlet and outlet pressures and temperatures. From this information, the signals are conditioned to provide on-line viscosity monitoring system which is related to the product melt index as is known in the art. This signal is then used to
5 monitor the product melt index via viscosity monitoring and tied back into the reaction control system for closed-loop melt index control. Since the component instrumentation for carrying out the individual measurement of these variables is well known in the instrumentation art, a detailed description of them will not be presented. However, the manipulation of these data to achieve viscosity monitoring and production rate control will
10 be described in detail.

The gear pump horsepower is the sum of the volumetric pumping work and viscous dissipation work. The viscous dissipation work is primarily due to viscous dissipation work in the pump bearings. Assuming all the viscous dissipation takes place in the pump bearings, the total horsepower can be represented by:

$$HP = \mu \gamma VA + Q\Delta p \qquad [1]$$

where:   $\mu$ = material viscosity in bearings;
$\gamma$ = shear rate in bearings;
$V$ = surface velocity of shaft in bearings;
20 $A$ = total surface area of shaft in bearing = $\pi LD$
$Q$ = volume of material being pumped; and
$\Delta p$ = pressure differential across the pump.

The total horsepower can also be represented by:

$$HP = 2\pi TN \qquad [2]$$

25 where:   $T$ = torque; $N$ = rotational speed.

Furthermore, the shear rate ($\gamma$) can be represented by:

$$\gamma = \pi DN \div C \qquad [3]$$

where:   $D$ = bearing diameter; $C$ = bearing clearance; and $Q$ can be expressed by:

$$Q = qN \qquad [4]$$

30 where:   $q$ = displacement/rev.

Combining these equations and using constants for the fixed parameters results in the following relationship:

$$\mu = k_1 \frac{T}{N} - k_2 \frac{\Delta P}{N} \qquad [5]$$

where:

$$k_1 = \frac{2C}{\pi^2 D^3 L} \qquad \text{and} \qquad k_2 = \frac{qC}{[\pi D]^3 L}$$

45 The last term

$$(k_2 \frac{\Delta P}{N})$$

50 can be eliminated for a simplified model to provide:

$$\mu = k_1 \frac{T}{N} \qquad [6]$$

In plant experiments, the torque and speed measurements produced viscosity determinations which agreed closely with the laboratory melt index analysis of the materials being processed.

60 The model can be modified to include product temperature effects on the viscosity monitoring systems by measuring the product temperature at the inlet or outlet of the pump. This modification has only a slight effect on the viscosity determinations since the temperature of the material in the bearings will reach a temperature which is dependent primarily upon the pump speed and material viscosity rather than the pump inlet or outlet temperatures. In effect, the temperature variations of the product being processed will have
65 a small effect upon the on-line viscosity determinations.

Extruder 102 includes a screw 102A, which is driven by motor 102B and extends coaxially within a tubular housing 102C from an input hopper 102D at one end to the media free space adjacent the gears. Preliminary mixture of the additive and melt is achieved in the terminal end of the extruder, by means of a high pressure melt feedback conduit 104 which extends from the outlet of the gear pump to the intermediate porti n of the extruder. In this manner the melt and additives are mixed in the last few flights of the extruder screw and introduced into the media free space for final mixing with the polymer in the gear pump. Conduit 104 may be either sized to provide proper feedback rate or may be equipped with an orifice plate or valve to provide variable feedback.

In addition to additive injection at the gear pump, additives may also be introduced through the top of vent stack 22. In the case of solid additives, they may be sprinkled over the surface of the polymer melt where the heat of the polymer melts the additives. The thus melted additives are mixed with the polymer as the material passes through the shear field in the gear pump.

The mixing of additives and polymer, whether introduced through vent stack or gear pump, is accomplished in the pump by the shear actions induced in the flow patterns within the pump, particularly as the material enters and is subsequently displaced from the gear tooth cavities.

For materials requiring a higher degree of mixing than performed by the gear pump, a static mixer, e.g., one of the type known commercially as a Kenics mixer, may be connected to the discharge of the gear pump to provide further mixing.

The gear pumps described above may also be utilized in compounding systems to increase the capacity and lower the operating costs. Compounding systems are similar to a recovery system in that more than one operation is performed by the compounding system. Compounding involves fluxing and mixing and in some cases pumping.

Compounding systems using extruders, whether single-screw or multiple-screw, are modified so that only the fluxing and mixing operations are performed by the extruder. The material is then fed to a gear pump for the pumping operation.

Figures 8A and 8B illustrate schematically two compounder-gear pump systems, 200 and 250, respectively. System 200 includes a compounding mixer 205 which may be of the batch or continuous discharge type. Compounder 205 discharges material through outlet 206 into a gear pump 30 of the type described above. By relegating the pumping operation to gear pump 30, which is insensitive to viscosity fluctuation, increased compounding capacity and production rate are achieved with a reduced product temperature rise. Final temperature reductions of up to 80°C may be achieved by the utilizaton of gear pump 30 for the pumping operation.

The system 250 includes a compounder 252 of either the batch or continuous process type which discharges the polymer in the form of rope R from outlet 252A. The polymer rope is enclosed within a conduit 254 which extends from outlet 252A to the inlet of a roller equipped gear pump 130, described above, for pumping. An inert atmosphere such as nitrogen gas is supplied to the interior of conduit 254 from source 256 through line 258. Any excess gas is withdrawn from conduit 254 through line 254A. It will be appreciated that the inert atmosphere reduces the oxidative degradation of the polymer as it passes from the compounder to the gear pump.

The gear pump of the present invention may also be used in the ultimate fabrication of material from polymers. Figure 9 illustrates schematically a gear pump 30 closely coupled to a plasticating extruder 260 by conduit 262. Die or mold 265 is used generically to cover both a restrictor for the fabrication of continuous products 266 having a cross-section determined by the restrictor, e.g. film, pipes, structural beams, and a mold for the fabrication of molded articles. In the latter case, a control valve 264 is utilized in line 263 connecting pump 30 to die 265 to pulse polymer into the die mold 265.

The gear pump 30 is the final element for promoting polymer melt flow into the die 265. The use of the gear pump to provide either continuous pressurized polymer for continuous extrusion or discrete charges of pressurized polymer for molding articles provides lower energy consumption for the fabrication system than comparable screw extruder or pressure cylinder method, respectively.

The basic modular gear pumps 30 and 130, described above, may be further formed by modular components to increase the utility and flexibility. Various other modular configurations will now be described.

Modularity may be achieved in a number of ways including: (a) gear housing casting with modular body insert, Figures 10 and 11; (b) gear housing casting which is split to increase the axial bore width with modular inserts, Figures 12 and 13; (c) pump body fabricated of independent modular sections, Figures 17 and 18; and (d) modular and roller configurations, Figures 14-16A.

Figures 10 and 11 illustrate a gear pump 30 similar to the pump 130, described above,

which is equipped with feed rollers 152. Corresponding parts are designated by the same part designations described with pump 130.

As previously described, the contour of the media free space is a function of the viscosity of the particular polymer being pumped. It will therefore be appreciated that the ability to easily vary the media free space of a pump is highly desirable. Additionally, the ability to change the gear diameters (and thus the media free space expansion) is also desirable to accommodate the production rate of the reactor. To this end, pump 330 includes an inlet/cylinder insert 380 of generally trapezoidal shape which is nestably received in a complementary cutout 381 within gear housing 52 which extends through the entire housing. Insert 380 is retained within cutout 381 by the overhanging portion 151 of inlet structure 150 and fasteners (not shown) and defines the media free space chamber 358 at its inner surface.

Insert 380 also defines wiper portions 368 immediately adjacent each roller 152A and seal zones 375 adjacent the discharge outlet 103. Thus, the insert 380 serves the functions of several of the previously described structural elements. But, in addition, insert 380 also mounts the bearing 71 within cylindrical bores 371A and defines the discharge outlet 103.

Thus, insert 380 together with herringbone gears 70, bearing 71 and end plates 72 form a removable package which can be custom designed for a particular polymer viscosity and production rate. Insert 380 may also be easily heat treated or plated for desired characteristics.

Pump 330 has certain other modifications over pump 130 including the deletion of feedback conduit 104 which, if desired, may be included. Additionally, additive extruder 102 has been relocated to the position of additive port 100 and an additive port 390, which may also include a screw extruder, has been located at the mixing zone parallel to the axis of gear rotation.

Figures 12 and 13 illustrate a pump 430 in which the gear housing 452 is cast in two half sections which are symmetrical axially about a plane perpendicular to the gear axis to permit axial variation of gear width. The two halves are secured together by axially extending bolts or the like (not shown). Housing 452 includes a thickened side wall 460 to accommodate a plurality of heat transfer passages 461 which extend laterally therethrough and are interconnected by vertical passages 462, Figure 13. Steam or other heat transfer (heating or cooling) is circulated through passages 461 and 462 to control the temperature of the pump.

Similar to pump 330, pump 430 includes an insert 480 which is retained in a complementary shaped cutout 481 within housing 452 by the overhanging portion 151 of inlet structure 150 and fasteners. Insert 480 defines the media free space chamber, seal zone 475 at its inner surface 458, and outlet 103. Additionally, insert 480 mounts the herringbone gear shafts and bearing 71 in bores 471 to provide a removable assembly. In the event that an axially larger assembly is to be inserted within housing cutout 481, the two halves of housing 452 are detached and a modular housing insert is positioned therebetween. These modular housing inserts are described below in connection with Figure 14.

Since an axial enlargement of the housing 452 also enlarges the outlet 103, a modular outlet insert 403 may also be utilized. Insert 403 is retained in a rectangular cutout 403A at the base of housing 452 and held therein by fasteners (not shown). Insert 403 includes heat transfer conduits 461 and 462 which mate with those in housing 452. The use of the insert 403 provides a continuous mating surface for the flange connection of the outlet pipe 36 or other equipment to which the polymer is discharged.

The split housing 452 may also be formed to eliminate end plates 72. This is accomplished by machining bores 471 from the inside of insert 480 to provide a shoulder at the exterior end of the bore.

Figures 14-16 illustrate a further modular pump design in which not only the housing but also the gearing and feed rollers are modules. Pump 530 includes a split inlet structure 550, and split housing casing 552.

Inlet structure 550, Figure 14, includes a pair of plate-like structures 550A and 550B, having L-shaped interlock end portions 550G and 550D between which is located a pair of complementary-shaped inserts 550E which extend the axial dimension of the inlet structure. Plates 550A and 550B and inserts 550E are secured to the underlying gear housing 552 by fasteners 556.

Housing 552 is a modified version of housing 52 and includes an integral steam chest 554. Housing 552 is a pair of symmetrical "halves" 552A and 552B as described above in connection with Figure 13 and an intermediate insert 552C. The housing "halves" and insert underlie the inlet structure and are interconnected by fasteners 552D.

The interior surface of housing 552 defines a trapezoidal receiver 581 in which an insert 580 is located. Insert 580 is retained in receiver 581 by the overlying end portions 551 of inlet structure 550 and fasteners. The interior surface of insert 580 defines wiper portion

568, media free space chamber 558 and seal zones 575, as previously described. Insert 580 extends between the end portions 552A and 552B, Figure 16, across insert 552C. A modular outlet insert 503 is retained in cutout 503A in the gear housing portions by fasteners not shown. Insert 503 defines the outlet discharge 503B at its inner surface and abuts against a bottom flange portion 552E of the gear housing. Insert 580 in turn overlies the top surface of the flange portion 552E.

With reference to Figure 15, additive injection is provided by extruder 102 and conduit 390 at the inlet structure and may also be provided through conduit 590 (shown plugged).

The roller assemblies 652 and gear assemblies 670 are also modular in construction and are mounted on splined shafts 652A and 670A, respectively.

The modular arrangement of roller assemblies 652 and gear 670 enables the performance characteristics of the pump to be varied and also permits ready replacement parts. More particularly, the use of helical gears to form a herringbone gear pattern has several advantages:

(a) The choice of any helix angle can be accommodated due to the reduction of fabrication diffculties.

(b) The expanded choice of helix angles permits optimization of the gears with respect to varying physical properties of the reactor product mix.

(c) Gear segments can be varied to match reactor conversion rates.

(d) In order to facilitate additive dispersion, a smaller circular pitch gear can be employed.

With particular reference to Figures 14 and 16, each roller assembly 652 is formed by a pair of end rollers 652B having integral end gears 652C and a central cylindrical roller 652D. To increase the axial length of roller assembly 652 additional rollers 652D or different length rollers 652D are added to the assembly. Shafts 652A include stub shafts rotatably mounted in inlet structure 550 by bearing 653 having end thrust collars. As described above, gears 652C mesh with the underlying gear to provide conjoint rotation therewith.

Gear assemblies 670 are also modular and may be formed completely by helical gears 670B as illustrated by the right side gear assembly (as viewed in Figure 14). In this case, a central pair of helical gears are positioned symmetrically about the center of shaft 670A to form a herringbone pattern and additional helical gears are stacked axial therefrom. Thus an even number of helical gears form the herringbone pattern.

Alternatively, a central herringbone gear 670C as illustrated on the left gear assembly in Figure 14 may be used. In this case, helical gears 670B are positioned axially on both sides of the central herringbone gear 670C to form the herringbone pattern.

Thus, an unlimited variation of axial lengths for the roller and gear assemblies may be provided by the addition of roller and gear modules, respectively.

Gear shafts 670A are rotatably mounted in housing 552 by bearings which may be a collar bearing 653 or a journal bearing 671.

Figure 16A illustrates an alternative pump structure similar to Figure 16. Roller assembly 752 includes a segment shaft 752A formed by a plurality of threadably connected or butted segments 760 to allow axial enlargement by the addition of segments thereto. Each roller shaft 752A is driven independently of the gears 770 by drive 761. The roller surface is provided by multiple cylinders 752B which are keyed to the shaft segments for rotation therewith.

Gear assembly 770 includes a segment shaft 770A having hollow shaft segments 770B interconnected to end shaft 770D by a longitudinally extending bolt 770E. The exterior surface of shaft 770A is splined to retain helical gears 670B therein.

Figures 17 and 18 illustrate a further modular pump 830 which is close coupled to vent stack 22 by means of the inlet structure 850, thereby eliminating the necessity for section 22A and the attendant pressure loss. Inlet structure 850 includes an additive injection tube 829 which extends across and above the mesh line of the gears 870.

The internal configuration of the gear assembly may be of any of the types previously described, i.e., one piece or modular. Therefore, a detailed description of the assembly will not be repeated.

The basic attribute of modular pump 830 is the provision of five basic modules, a pair of gear housings 852 which are symmetrical about the mesh line of gears 870; a pair of plate-like end structures 860 which abut against each end of the housing 852 and extend downward therefrom; and an outlet structure 803 which abuts against the bottom of the housing 852 and is positioned between the end structures 860.

With reference to Figure 17, the pair of housings 852 have thickened side walls which include a plurality of axially extending heat transfer fluid passageways 853. The interior surface 858 of housing 850 defines the media free space chamber and seal zone 875, and outlet aperture, as previously described.

The end structures 860 carry the gear shafts 870A within bearings 871 and are fastened to

the housings 850 and outlet structure 803 by longitudinally extending bolts 876. As illustrated, outlet structure 803 is close coupled to a mixer module 900, which is also fastened to end structures 860 by bolts 876.

In addition, end structures 860 include a manifold network 901 having an inlet 901A and outlet 901B for interconnecting the passages 853 in housings 850 and supplying the heat transfer medium thereto and to passage 903 in outlet structure 803. The manifold 901 may be directly abutted against the passages, or a nipple coupling 905 may be provided. An additional heat transfer network 904, having an inlet 904A and outlet 904B is provided for the depending portions of the end structures.

Pump 830 provides several advantages including:
(a) Interchangeable media free space configurations for particular product mixes.
(b) The individual replacement of worn or corroded sections.
(c) Facilitation of finishing and treatment of internal surfaces.
(d) Provision of mixing/dispersion systems in the outlet module as required for additive applications.

These and other modifications may be made to the present invention by those skilled in the art without departing from the scope of the present invention claimed in the appended claims.

WHAT IS CLAIMED IS:

1. A gear pump for pumping highly viscous media comprising: housing means defining an inlet passage at one end and an outlet passage at an opposite end, and a chamber therebetween; a pair of pump gears located within said chamber having intermeshing teeth and being rotatably mounted in said housing, the walls of said chamber and said pump gears defining therebetween a free space to receive viscous media and a wall of of said chamber and each of said gears defining a gear sealing zone adjacent the outlet, each zone having a minimum length circumferentially of the respective gear equal to the circumferential distance between two adjacent gear teeth across the full axial length of said gears at the outside perimeter of said gears; the portion of said outlet adjacent said sealing zones having a cross-sectional area of from 0.2 to 2.0 times the product of the gear width and the gear tooth height.

2. The pump in accordance with claim 1 wherein said outlet is generally rectangular in shape having a width equal to the gear face width and a length equal to the gear tooth height with the major dimension being parallel to the gear axis.

3. The pump of claim 1, wherein said media free space expands from the end of said seal zone remote from the outlet such that an increasing radius is produced at least to the plane of the gear axes, whereby a pressure gradient is created to fill the gear cavities with said viscous media.

4. The pump of claim 3, wherein the ratio of media free space clearance to the circumferential distance from said seal zone is in the range of about 0.2 to 0.9.

5. The pump of claim 1, wherein said gears have a herringbone pattern.

6. The pump of claim 5, wherein the helix angle of said gears is between 5° and 30°.

7. The pump of claim 6, wherein said helix angle is between 7° and 10°.

8. The pump of claim 5, wherein each of said herringbone pattern gears includes a central herringbone gear and a pair of helical gears, each of said helical gears having a helix angle equal to the herringbone gear helix angle and being positioned in coaxial end-to-end relationship with said herringbone gear to form said herringbone pattern.

9. The pump of claim 5, wherein each of said herringbone pattern gears comprises a plurality of helical gears; said gears being arranged symmetrically to form a herringbone pattern.

10. The pump of claim 5, wherein said gears are mounted on a segmented shaft.

11. The pump of claim 1, further including means in said housing means for introducing an additive to said viscous media.

12. The pump of claim 11, wherein said introducing means includes an extruder having its outlet positioned adjacent said free space and its inlet exterior of said housing.

13. The pump of claim 12, wherein said housing means defines a feedback chamber extending from said pump outlet to a point upstream of said extruder outlet, whereby polymer may be initially mixed with the additive in said extruder.

14. The pump of claim 1, wherein introducing means is positioned to introduce the additive at a location upstream of said chamber.

15. The pump of claim 1, further including a pair of feed rollers rotatably mounted upstream of said pair of gears, the axis of each roller being substantially parallel to the axis of the associated gear, and said rollers being spaced apart to define a media nip substantially coplanar with the mesh line of said gears; said housing means including wiper means adjacent each roller; and means for rotating said rollers to draw said media into and feed said gears.

16. The pump of claim 15, wherein said means for rotating said rollers includes a gear train operatively coupling each roller to its associated gear, whereby the rollers are driven conjointly with said gears.

17. The pump of claim 15, wherein said means for rotating said rollers includes a drive means operatively coupled to said rollers, whereby said rollers are driven independently of said gears.

18. The pump of claim 15, wherein said rollers are modular in construction, whereby the axial length thereof may be varied.

19. The pump of claim 1, wherein said media free space is defined by the interior surface of said housing such that the free space increases in cross section from said seal zone in a smooth continuous curve, to a location upstream of said gears.

20. The pump of claim 1, wherein said housing is modular and includes two interconnected portions.

21. The pump of claim 20, wherein said housing modular portions are symmetrical about the plane extending transversely to said gear axes.

22. The pump of claim 21, further including modular housing insert means interposed between and complementary to said modular portions.

23. The pump of claim 20, wherein said housing modular portions are symmetrical about the mesh line of the gears.

24. The pump of claim 20, wherein said housing includes removable central insert means, said insert means defining said media free space at its inner surface.

25. The pump of claim 24, wherein said insert means extends the full axial dimension of said gear face width.

26. The pump of claim 1, wherein said housing comprises a pair of modular housing portions defining said media free space at their interior surfaces and symmetrical about the mesh line of said gears; a pair of end structure modules abutting the axial ends of said housing portions and rotatably mounting said gears, said end structures extending beyond said housing portions; and a modular outlet structure nested with the outlet of said housing portions between said end structures, and means interconnecting said modules.

27. A gear pump for pumping highly viscous media provided to the pump in rope-like strand form comprising: housing means defining an inlet passage at one end and an outlet passage at an opposite end, and a chamber therebetween; a pair of pump gears located within said chamber having intermeshing teeth and being rotatably mounted in said housing, the walls of said chamber defining a free space adjacent the surface of said gears to receive viscous media, and a wall of said chamber adjacent said outlet including a gear sealing zone having a minimum length circumferentially of the respective gear equal to the circumferential distance between two adjacent gear teeth across the full axial length of said gears at the outside perimeter of said gears; the portion of said outlet adjacent said sealing zone having a cross-sectional area of from 0.2 to 2.0 times the product of the gear and the gear tooth height; a pair of feed rollers rotatably mounted in said chamber upstream of said gears, the axis of each roller being substantially parallel to the axis of the associated gear and said rollers being spaced apart to define a media nip substantially coplanar with the mesh line of said gears, and means for rotating said gears and rollers, whereby said rope strand is drawn into and feeds the gear cavities and is thereafter pumped by said gears.

28. The pump in accordance with claim 27, wherein said outlet is generally rectangular in shape having a width equal to the gear face width and a length equal to the gear tooth height with the major dimension being parallel to the gear axis.

29. The pump of claim 27, wherein said media free space expands from the end of said sealing zone remote from the outlet such that an increasing hydraulic radius is produced at least to the plane of the gear axes, whereby a pressure gradient is created to fill the gear cavities with said viscous media.

30. The pump of claim 29, wherein the ratio of media free space clearance to the circumferential distance from said seal zone is in the range of about 0.2 to 0.9.

31. The pump of claim 27 wherein said gears have a herringbone pattern.

32. The pump of claim 31, wherein the helix angle of said gears is between 5° and 30°.

33. The pump of claim 32, wherein said helix angle is between 7° and 10°.

34. The pump of claim 27, wherein said means for rotating said rollers includes a gear train operatively coupling each roller to its associated gear, whereby the rollers are driven conjointly with said gears.

35. The pump of claim 27, wherein wiper means are provided adjacent each of said rollers.

36. Apparatus for compounding highly viscous media which comprises compounding means having an inlet and an outlet, a gear pump communicating with the outlet of said compounding means to receive the viscous material therefrom and pump it for further processing, said gear pump including housing means defining an inlet and an outlet

interconnected by a gear chamber, a pair of pump gears located within said chamber having intermeshed teeth and rotatably mounted in said housing; the walls of said chamber defining a free space to receive viscous media and a gear sealing zone adjacent said outlet, said free space having a radius from the axes of the gears, which increases upstream of the sealing zone, the portion of said outlet adjacent the sealing zone having a cross-sectional area of from 0.2 to 2.0 times the product of the gear width and the gear tooth height.

37.    Apparatus in accordance with claim 37, wherein said outlet is generally rectangular in shape having a width equal to the gear face width and a length equal to the gear tooth height with the major dimension being parallel to the gear axis.

38.    Apparatus of claim 36 wherein said compounding means is a batch compounder.

39.    Apparatus of claim 36, wherein said compounding means is a continuous flow compounder.

40.    Apparatus of claim 39, wherein said continuous compounder includes an extruder.

41.    Apparatus of claim 36, wherein said gear pump inlet is directly coupled to said compounder outlet.

42.    Apparatus of claim 36, wherein said compounder is arranged to discharge the media in continuous rope form; said pump inlet being spaced downstream from said compounder outlet; and conduit means coupling said compounder outlet to said pump inlet.

43.    Apparatus of claim 42, wherein further means are provided for charging the area enclosed by said conduit with an inert fluid medium, whereby oxidative degradation of the rope media is reduced during its passage therethrough.

44.    Apparatus of claim 42, wherein said pump further includes a pair of rollers in said housing substantially parallel to and upstream of said gears, and means for driving said rollers, whereby said rope is drawn into and feeds said gears.

45.    A polymer fabrication system comprising the combination of gear pump having an inlet, an outlet and a gear chamber, arranged to receive polymer from a source, and a molding means communicating with said outlet of said pump to receive pressurized polymer therefrom, said gear pump having a pair of intermeshing rotatable gears positioned in said gear chamber; the gear chamber having a sealing zone adjacent said outlet and having a free space to receive viscous media, of an increasing cross-section extending upstream from said sealing zone; the portion of said outlet adjacent the sealing zone having a cross-sectional area of from 0.2 to 2.0 times the product of the gear width and the gear tooth height.

46.    The system of claim 45, wherein said molding means is an extrusion die, whereby continuous fabrication is provided.

47.    The pump of claim 1, wherein said outlet communicates with the inlet of a mixer.

48.    A process for the production of a polymer wherein a liquid polymer melt and entrained volatile monomer are delivered from a reactor to a product receiver for partial flashing of the volatile monomer, and comprising the steps of transferring the polymer from the outlet of said product receiver to the inlet of a vent stack; flashing substantially all of the remaining volatile monomer from the melt in the vent stack; discharging said polymer melt from the outlet of the vent stack into the inlet of a gear pump having a pair of intermeshing gears bounded by a free space chamber to receive polymer melt, having a decreasing radius from the axes of the gears toward the pump discharge and having a discharge outlet having a cross-sectional area of from 0.2 to 2.0 times the product of the gear width and the gear tooth height; and sensing and maintaining the level of liquid in said stack to provide a pressure head to said gear pump.

49.    The process of claim 48, further including sensing the torque and rotational speed operating parameters of said gear pump, utilizing the sensed parameter to calculate the viscosity of the polymer melt according to the formula

$$\mu = K_1 \frac{T}{N}.$$

where $\mu$ is the viscosity, $K_1$ is a proportionality constant for the pump, and T,N are the torque and rotational speed parameters.

50.    The process of claim 48, further including the step of introducing an additive into said polymer at said gear pump, whereby said additive is mixed into said polymer during pumping action.

51.    The process of claim 50, wherein said additive is introduced into the polymer melt adjacent said gears.

52.    The process of claim 51 wherein said additive introduction is performed by conveying the additive in a screw extruder.

53.    The process of claim 52, further including the step of feeding a portion of polymer from the discharge of said pump into said screw extruder, whereby a partial mixing of

additive and polymer is performed. prior to introduction of the additive into the pump.

54. The process of claim 48, further including sensing the torque, rotational speed, operating parameters and pressure differential of said gear pump; utilizing th sensed parameters to equate to the viscosity of the polymer melt according to the formula

$$\mu = K_1 \frac{T}{N} - K_2 \frac{\Delta p}{N}$$

where $\mu$ is the viscosity, $K_1$ and $K_2$ are proportionality constants for the pump, T, N are the torque and rotational speed parameters, $\Delta p$ is pressure differential, and generating a control signal from said calculated viscosity to provide closed loop viscosity control of said reactor.

55. A process substantially as hereinbefore described with reference to the accompanying drawings.

56. A pump substantially as hereinbefore described with reference to the accompanying drawings.

57. Apparatus substantially as hereinbefore described with reference to the accompanying drawings.

58. A system substantially as hereinbefore described with reference to the accompanying drawings.

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FIG.1.

FIG.2.

FIG.3.

FIG.4.

FIG.5.

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FIG.6.

FIG.7.

FIG.8A.

FIG.8B.

COMPOUNDING MIXER

GEAR PUMP

COMPOUNDING MIXER

GAS

FIG.9.

FIG.10.

FIG.11.

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FIG.12.



FIG.13.

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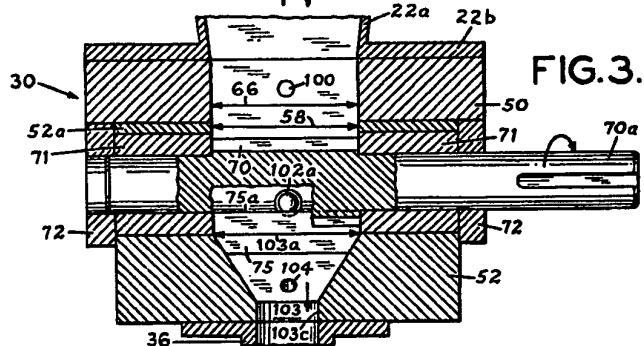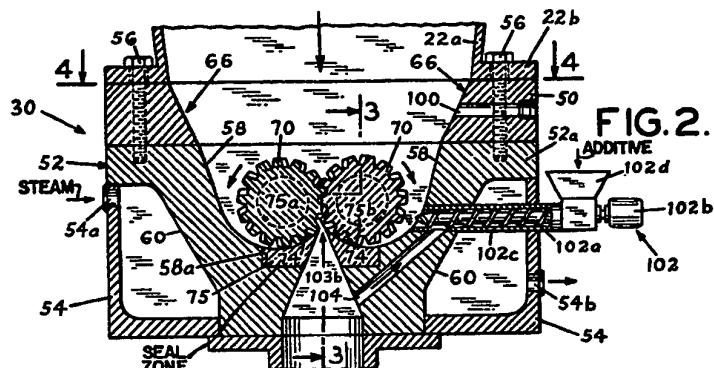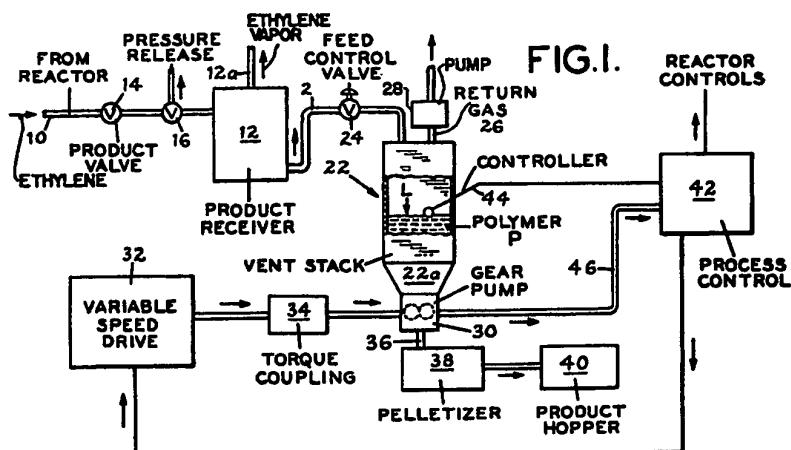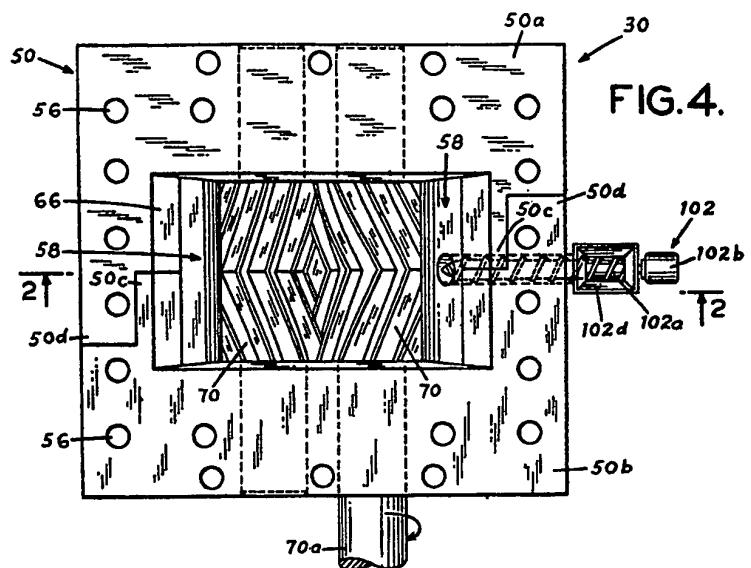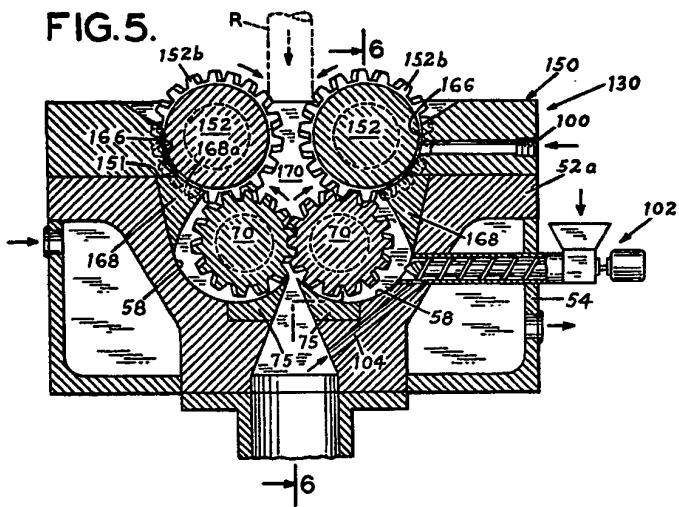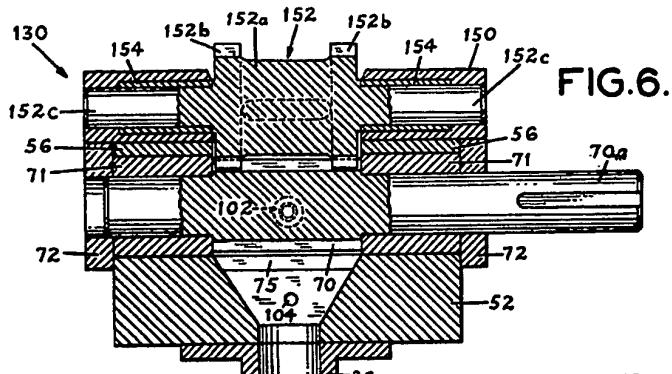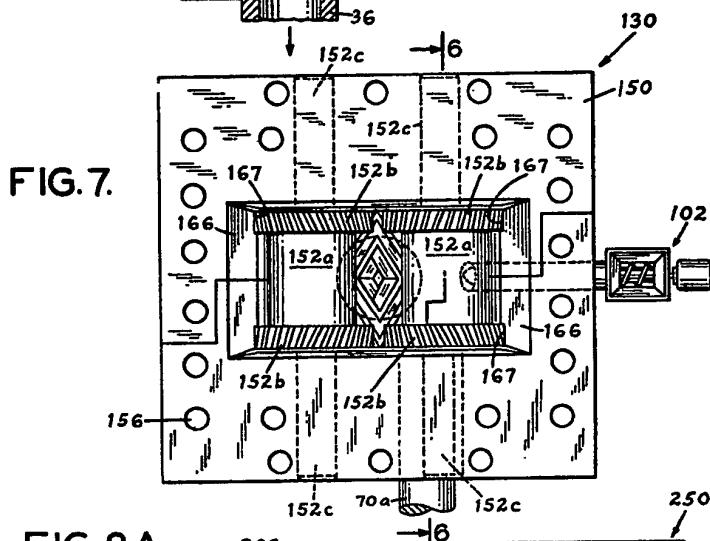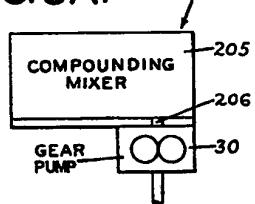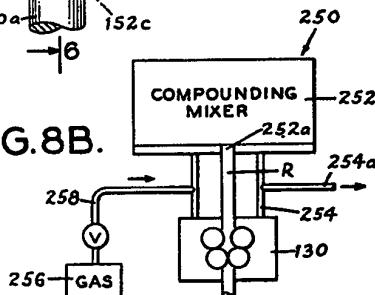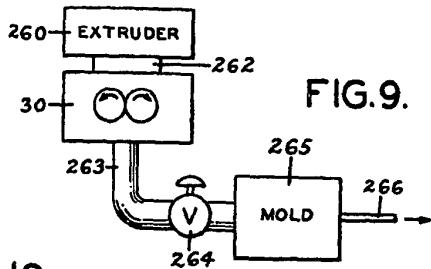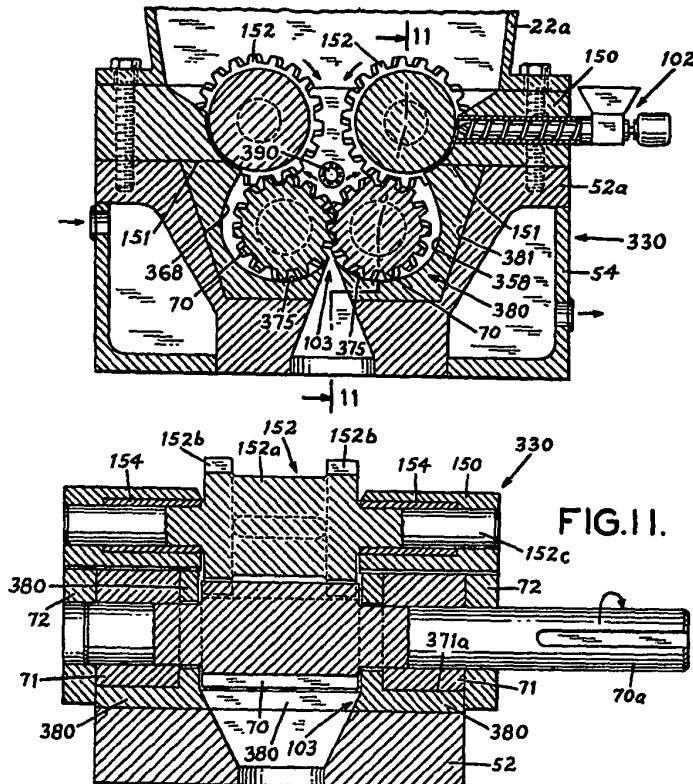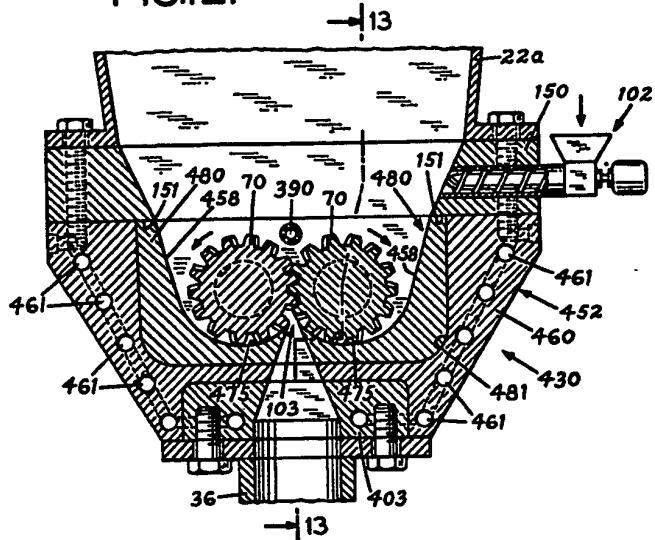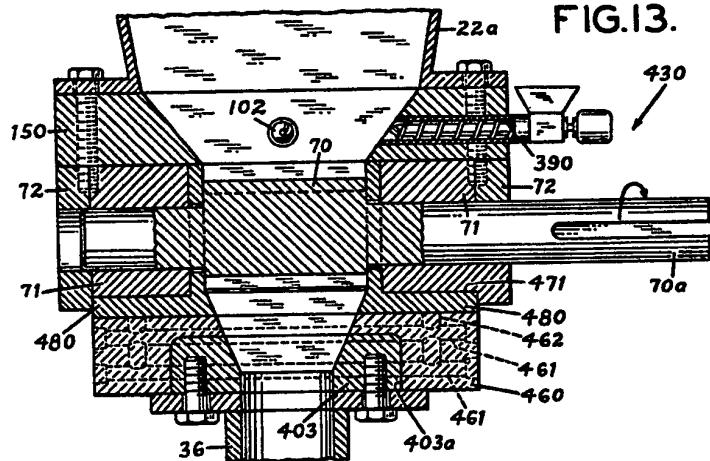
FIG.14.



FIG.15.

## FIG.16.



## FIG.16A.

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FIG.17.

FIG.18.